nature portfolio

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Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our Editorial Policies and the Editorial Policy Checklist.

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☐	☒	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☐	☒	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☐	☒	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☐	☒	A description of all covariates tested
☒	☐	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☐	☒	For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☒	☐	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☐	☒	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	Data used to calculate trends of the optimum N rates were sourced from yield response to nitrogen rate field experiments. This data was further enhanced using the Agricultural Production Systems Simulator (APSIM) version 7.9 to simulate each cropping system's nitrogen dynamics, these variables included nitrate leaching, nitrous oxide emissions, grain nitrogen concentration, and net soil mineralization. APSIM is an open source framework.
Data analysis	All analysis was conducted in R version 4.1.2. We used the lme (version 3.1-164) function within the nlme package to determine trends in the optimum N rates by treating an individual location as a random effect in the model. Trends of explanatory variables and optimum N rates within a location and rotation were fit using a simple linear model as they lacked factors for added complexity. The significance of an individual slope was tested using a p-value and considered significant at the p-value < 0.05 level. All figures were constructed using the ggplot2 (version 3.5.1).

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

The data supporting the findings of this study are available within the article and supplementary information and been deposited at Zenodo repository: https://doi.org/10.5281/zenodo.14037090.

Human research participants

Policy information about studies involving human research participants and Sex and Gender in Research.

Reporting on sex and gender	N/A
Population characteristics	N/A
Recruitment	N/A
Ethics oversight	N/A

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	We synthesized data from 14 long-term maize yield response to N rate trials carried out in the two top maize-producing states within the United States of America. The Illinois experiments started in 1999 and ended in 2008, while the Iowa experiments started in 2000 and ended in 2021. Each location contained continuous maize and maize-soybean systems and a minimum of five to seven N rates. Each experiment followed a split-plot design with crop rotation as the main plot and N-rate as the sub-plot, containing four replications. Across locations and treatments, grain yield was reported at 15.5% moisture. Nitrogen fertilizer rates ranged from 0 to 268 in Iowa and from 0 to 252 kg N/ha in Illinois, with all nitrogen applications occurring within ±2 weeks of maize planting. Moreover, we used the Agricultural Production Systems sIMulator to estimate N losses, N mineralization, grain N, and depth to the watertable, per site, year and cropping system. To further enhance our understanding of how the economic optimum nitrogen rate has changed over time, we retrieved 155 additional values from response equations in the Corn Nitrogen Rate Calculator for Iowa that included both maize rotations. These data were selected from the Corn N Rate Calculator reflect single-year N rate responses to compare temporal trends between long-term and single-year datasets. We also used the recently reported EONR temporal trend for maize-soybean in Illinois (n = 21).
Research sample	Optimum nitrogen rates were determined by analyzing long-term maize yield response to nitrogen trials conducted on university-owned and managed research farms in Iowa and Illinois, USA. The dispersion of field experiments was representative of the soils, crop management, and weather patterns of the main maize-producing areas of their respective state and year studied.
Sampling strategy	The sample size was based on availability and not statistical sampling. However, with 379 optimum N rate estimations across 14 sites and roughly 20 years, we believe our sample size is large enough to determine trends within the optimum nitrogen rates for the two crop rotations tested during the sampling period.
Data collection	Measured maize yield data per site, year, crop rotation, nitrogen rate, and replication was mechanically harvested at the end of each growing season by university managed personnel and reported at a 15.5% grain moisture content. Nitrogen losses (i.e., nitrate leaching and nitrous oxide emissions) were simulated using the Agricultural production systems simulator (APSIM). The model calibration and validation per site can be found in (Baum et al., 2023).
Timing and spatial scale	Optimum nitrogen rates were estimated annually in Iowa from 2000 to 2021 and from 1999 to 2008 in Illinois. Each state consisted

of 7 experimental trials per year. Spatial scale of experiments are shown in Fig. 1 of the article with direct coordinates per experimental location being reported within the Zenodo digital repository: https://doi.org/10.5281/zenodo.14037090.

Data exclusions	The Iowa locations received zero nitrogen fertilizer in all plots in 2017 and 2018; thus, those years were excluded from the analysis. However, experimentation resumed under the same design in 2019. To limit any potential residual effect of the years 2017 and 2018 on our analysis the year 2019 was also excluded.
Reproducibility	N/A
Randomization	N/A
Blinding	N/A

Did the study involve field work? [x] Yes [ ] No

Field work, collection and transport

Field conditions	Nitrogen fertilizer rates ranged from 0 to 268 in Iowa and from 0 to 252 kg N/ha in Illinois and were applied as a single application around the time of maize planting ±2 weeks (mid-April to late-May). Furthermore, the mean annual precipitation was 922 ± 268mm per year, and the mean sum of growing degree days (base = 8°C) between planting and maturity was 1,961 ± 173 oC-d. Additional soil information on the experiments can be found in Baum et al. (2023), and annual crop management factors such as planting date, plant density, and fertilizer application date can be found in the Zenodo digital repository using the hyper link https://doi.org/10.5281/zenodo.14037090.
Location	Coordinates of each field are listed below, and displayed on Fig 1 within the article. Ames, IA. Latitude = 42.012, Longitude = -93.743 Brownstown, IL. Latitude = 38.952, Longitude = -88.958 Chariton IA. Latitude = 40.972, Longitude = -93.420 Crawfordsville, IA. Latitude = 41.203, Longitude = -91.492 DeKalb, IL. Latitude = 41.839, Longitude = -88.862 Dixon Springs-lowland, IL. Latitude = 37.459, Longitude = -88.720 Dixon Springs-Upland, IL. Latitude = 37.426, Longitude = -88.664 Kanawha, IA. Latitude = 42.915, Longitude = -93.789 Lewis, IA. Latitude = 41.328, Longitude = -95.181 Monmouth, IL. Latitude = 40.934, Longitude = -90.727 Nashua, IA. Latitude = 42.942, Longitude = -92.568 Perry, IL. Latitude = 39.803, Longitude = -90.822 Sutherland, IA. Latitude = 42.928, Longitude = -95.539 Urbana, IL. Latitude = 40.082, Longitude = -88.225
Access & import/export	N/A
Disturbance	N/A

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study	
[x]	[ ]	Antibodies
[x]	[ ]	Eukaryotic cell lines
[x]	[ ]	Palaeontology and archaeology
[x]	[ ]	Animals and other organisms
[x]	[ ]	Clinical data
[x]	[ ]	Dual use research of concern

Methods

n/a	Involved in the study	
[x]	[ ]	ChIP-seq
[x]	[ ]	Flow cytometry
[x]	[ ]	MRI-based neuroimaging